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Core Curriculum

A Summary of Recommendations for Occupational Radiation Protection in Interventional Cardiology

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The radiation dose received by cardiologists during percutaneous coronary interventions, electrophysiology procedures, and other interventional cardiology procedures can vary by more than an order of magnitude for the same type of procedure and for similar patient doses. There is particular concern regarding occupational dose to the lens of the eye. This document provides recommendations for occupational radiation protection for physicians and other staff in the interventional suite. Simple methods for reducing or minimizing occupational radiation dose include minimizing fluoroscopy time and the number of acquired images; using available patient dose reduction technologies; using good imaging-chain geometry; collimating; avoiding high-scatter areas; using protective shielding; using imaging equipment whose performance is controlled through a quality assurance program; and wearing personal dosimeters so that you know your dose. Effective use of these methods requires both appropriate education and training in radiation protection for all interventional cardiology personnel, and the availability of appropriate protective tools and equipment. Regular review and investigation of personnel monitoring results, accompanied as appropriate by changes in how procedures are performed and equipment used, will ensure continual improvement in the practice of radiation protection in the interventional suite. These recommendations for occupational radiation protection in interventional cardiology and electrophysiology have been endorsed by the Asian Pacific Society of Interventional Cardiology, the European Association of Percutaneous Cardiovascular Interventions, the Latin American Society of Interventional Cardiology, and the Society for Cardiovascular Angiography and Interventions. © 2012 Wiley Periodicals, Inc.

Key words: radiation safety; radiation dosage; radiation monitoring; protective devices; lens opacities

INTRODUCTION

This is a summary of the "Recommendations for Occupational Radiation Protection in Interventional Cardiology" [1], endorsed by the following societies: Asian Pacific Society of Interventional Cardiology (APSIC), the European Association of Percutaneous Cardiovascular Interventions (EAPCI), the Latin American Society of Interventional Cardiology (SOLACI),

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and the Society for Cardiovascular Angiography and Interventions (SCAI).

In the interests of brevity, the terms interventional cardiology and interventional cardiologists in this summary are intended to include electrophysiology and electrophysiology physicians, respectively.

Interventional cardiology procedures are performed in ever increasing numbers around the world. Further, because of continual improvements in these techniques, they are being performed on ever more complex disease, with a greater number of lesions to treat and in difficult angiographic situations. The benefits of interventional cardiology to patients are both extensive and beyond dispute, but many of these procedures also have the potential to produce patient radiation doses high enough to cause radiation effects and occupational doses high enough to cause concern.

The radiation dose received by interventional cardiologists can vary by more than an order of magnitude for the same type of procedure and for similar patient doses. There is particular concern regarding occupational dose to the lens of the eye.

This summary of the full text of the recommendations [1] is intended to provide an overview of the medical physics relevant to occupational radiation protection and to provide advice and guidance to interventional cardiologists, nurses, and technologists who perform cardiac procedures with the guidance of ionizing radiation.

MEASUREMENT OF OCCUPATIONAL EXPOSURE IN THE CARDIAC LABORATORY

The aim of radiation protection is to prevent deterministic radiation effects occurring in organs and tissues, and to limit the risk of stochastic effects (primarily cancer) to a level that is not considered unacceptable. To this end occupational dose limits are set, and regulatory bodies require that a worker does not receive occupational exposure higher than the dose limits. But in addition, regulatory bodies also require the implementation of the principle of optimization of protection and, as a result, it is expected that occupational doses would be considerably lower than the dose limits.

Hence, persons working with radiation in the interventional cardiology laboratory need to know what occupational doses they are receiving. This is the ultimate "litmus test" of whether good occupational radiation protection practice is occurring or whether improvements need to take place. The occupational doses of interest are those to particular organs or tissues (specifically, equivalent doses to the skin, lens of the eye, and hands and feet) and to the whole body (the effective dose).

Using Dosimeters in the Cardiac Laboratory

Measurements of occupational doses are obtained using dosimeters worn by personnel while they are involved in interventional cardiology procedures. It is recommended that persons involved in interventional cardiology procedures are monitored on a monthly basis, as this will facilitate relatively quick identification of practices that have led to high personal dose and thence to subsequent implementation of work habit changes.

Requirements for the number and placement of dosimeters for monitoring in interventional cardiology vary from country to country. It is acknowledged that the use of two dosimeters can lead to some practical issues—potential increased likelihood of the loss of dosimeters and the possibility of dosimeters and positions being swapped. Further, it can be argued that one dosimeter worn appropriately is better than two used inappropriately. However, it is recommended that interventional cardiology departments develop a policy that personnel wear two dosimeters, one under the apron and one at collar level outside the lead apron. A dosimeter worn on the front of the torso between shoulder and waist level, under the protective apron, will provide a good estimate of effective dose. A collar dosimeter worn over protective garments (apron, thyroid shield) can provide a reasonable estimate of the dose delivered to the surface of the unshielded skin and to the lens of the eye. Assuming no protection is used, the dose received by specific tissues can be better estimated by placing a dosimeter on or near the tissue of interest. For example, hand doses may be monitored using a ring dosimeter.

For pregnant workers who have declared their pregnancy, conceptus dose can be estimated using the dosimeter worn under the protective apron. Sometimes an additional dosimeter is placed on the mother's abdomen, again under her radiation protective clothing.

Inaccurate occupational exposure assessment can arise from dosimeters not being used correctly. For example, a dosimeter may be worn in the wrong location on the body or it may be worn part of the time outside the apron and part of the time underneath, or it may be worn back-to-front for some or all of the time. The dosimeter may be left, when not being used, in an area where it is exposed to further radiation. Individuals may also forget to wear their dosimeter or may deliberately not wear their dosimeter some or all of the time. All of these actions would result in a dosimeter value that leads to an incorrect estimate for occupational dose.

Dose Limits

Dose limits for occupational exposure are expressed in equivalent doses for preventing deterministic effects in specific tissues and as the effective dose for limiting the likelihood of stochastic effects throughout the body. The current occupational dose limits recommended by the ICRP [2,3], and mandated in the International Basic Safety Standards [4], are given in Table I.

Additional restrictions apply to the occupational exposure of pregnant staff. For women who are pregnant, the ICRP recommends that the standard of protection for the conceptus should be broadly comparable to that provided for members of the general public [3]. This should not preclude a pregnant physician, who is following good radiation protection practice, from performing procedures in the laboratory.

TABLE I. Dose Limits for Occupational Exposure (adapted from ICRP [2,3])

Dose quantity	Occupational dose limit
Effective dose	20 mSv per year averaged over five consecutive years (100 mSv in 5 years), and 50 mSv in any single year
Equivalent dose in:	
Lens of the eye	20 mSv in a year, averaged over defined periods of five years, with no single year exceeding 50 mSv
Skin[a]	500 mSv in a year
Extremities (hands and feet)	500 mSv in a year

[a]Averaged over 1 cm^2 of the most highly irradiated area of the skin.

EVALUATION OF PERSONAL DOSIMETRY DATA

Interventional cardiologists are unavoidably exposed to radiation in the performance of their duties. However, a busy interventional cardiologist who takes all appropriate radiation protection precautions is unlikely to have an effective dose exceeding 10 mSv/year and is more likely to be in the range 1–4 mSv/year.

The facility's radiation safety section or medical physics service should review the personal dose records of individual workers regularly. This review ensures that dose limits are not exceeded and that optimization of protection is occurring by evaluating whether each dose received is at the level expected for that worker's particular duties.

Investigation of high occupational doses may result in changes in practices that improve not only the safety of the individual but also the safety of patients and other staff as well. An investigation level of 2 mSv per month, using the reading from the collar dosimeter, is appropriate. It is important to remember that investigation levels are not dose limits, but rather are triggers to improve the practice of protection. The facility's radiation protection officer or a qualified medical physicist should contact the worker directly to determine the cause of the unusual dose and to make suggestions about how to keep the worker's dose as low as reasonably achievable (ALARA). The recent lowering of the ICRP dose limit for the lens of the eye is likely to trigger investigations of occupational exposure, with subsequent modification of practice in many interventional cardiology facilities.

Unexpectedly low occupational doses should also be investigated, as these may indicate that dosimeters are being worn incorrectly or not at all.

RADIATION PROTECTIVE TOOLS

The greatest source of radiation exposure to the operator and staff is scatter from the patient. Generally, controlling patient dose also reduces scatter and limits operator dose. Distancing yourself from the source of scatter affords some protection. However, the use of protective tools in interventional cardiology is needed to keep occupational radiation doses as low as reasonably achievable.

Combining various types of shielding (table-suspended drapes, ceiling-suspended screens, protective aprons, leaded eye-glasses, mobile shields, and disposable drapes) results in a dramatic dose reduction for the operator. This should be the norm, rather than the exception.

Scatter

The amount and direction of scattered radiation are affected by many factors, including patient size, gantry angulation, beam size, patient position, filtration, and fluoroscopic and image acquisition settings. Overall, in an unshielded environment, and for a C-arm gantry with the tube positioned under the table, the exposure is greatest below the table, less at the operator's waist level, and least at the eye level. However, substantial operator eye doses can be reached in unfavorable circumstances (large patient, high-dose fluoroscopy and image acquisition, gantry angulation), underscoring the importance of proper protection, including for the eyes.

In pediatric interventional cardiology, the interventional cardiologist may need to stay closer to the patient than for an adult during the use of radiation, and the procedure may involve the use of a bi-plane system. The higher scatter dose rates associated with being very close to the pediatric patient may be offset to some extent by the fact that the amount of scatter being generated in the first instance is less due to the lower dose rates needed to image a smaller patient and the use of smaller beam sizes. Nonetheless, protective tools are indicated.

The choice of arterial access (radial artery vs. femoral artery) can affect the radiation dose from scatter that an operator will receive—the closer the arterial access point is to the irradiated volume of the patient, the closer the operator is likely to stand to the source of scatter. Additional factors affect actual occupational exposure, including the use of protective garments and shielding, the amount of radiation used to perform the procedure and, for radial artery access, patient arm position.

Shielding

There are three types of shielding: architectural shielding, equipment-mounted shields, and personal protective devices. Architectural shielding is built into the walls of the cardiac laboratory. This type of shielding is not discussed further here. In addition, rolling and stationary shields which rest on the floor, constructed of transparent leaded plastic, are available and are useful for providing additional shielding for both operators and staff, including nurses and anesthesia personnel.

Equipment-mounted shielding includes protective devices suspended from the table and from the ceiling. Table-suspended drapes, because they hang from the side of the patient table between the under-table X-ray tube and the operator, substantially reduce operator dose. Unfortunately, they sometimes cannot be used if the X-ray gantry (C-arm) is in a steep oblique or lateral position.

Ceiling-suspended shields, generally constructed of a transparent leaded plastic, dramatically reduce occupational exposure, including operator eye dose, if they are positioned correctly during the procedure. The availability of more than one ceiling-suspended shield, or other movable form of shield, is indicated for the interventional cardiology room. New procedures can now involve operators on both sides of the table and, in any case, nurses and other personnel should have the opportunity to utilize shielding in addition to their protective clothing.

Disposable protective patient drapes can be adopted in high dose procedures when the suspended screen cannot be used.

Personal Protective Devices

Personal protective devices include aprons, thyroid shields, eyewear, and gloves. Protective wrap-around aprons with thyroid shields are the principal radiation protection tool for workers in interventional cardiology. They should be employed at all times. Aprons need to fit properly and consideration should be given to ergonomic aspects. Lead aprons also need to be cared for properly and stored on appropriate hangers when not in use. Lead aprons and other leaded protective clothing should be inspected before they are put into service and then periodically re-inspected to determine that they provide the shielding benefit for which they were designed.

TABLE II. Key Points for Safe Practice in Interventional Cardiology

- Minimize fluoroscopy time.
- Minimize the number of acquired images.
- Use available patient dose reduction technologies.
- Use good imaging-chain geometry.
- Use collimation.
- Position yourself in a low-scatter area.
- Use protective shielding.
- Use appropriate imaging equipment.
- Use imaging equipment whose performance is controlled through a quality assurance program.
- Obtain appropriate training.
- Wear your dosimeters and know your own dose!

Note: See text for details.

Leaded eyeglasses are an alternative to ceiling-suspended shields for eye protection. Leaded eye-glasses with protective side shields provide more protection than eye-glasses without these features.

The operator's hands should be kept out of the primary radiation beam. This remains the best way to protect the hands. Leaded gloves may seem useful for radiation protection on those rare occasions when the operator's hands must be in the primary radiation beam, but they do not provide protection in this situation.

As new protective devices become available, they should be evaluated critically for use in the cardiac laboratory and adopted if shown to improve radiation protection and reduce ergonomic hazards.

PRACTICAL ADVICE TO REDUCE OR MINIMIZE OCCUPATIONAL RADIATION DOSE

Decreasing patient dose will result in a proportional decrease in scatter dose to the operator and other personnel in the room. Therefore, techniques that reduce patient dose will generally also reduce your occupational dose. This is a "win-win" situation; you and your patient both benefit. In addition, there are techniques that can be used with interventional cardiology procedures to reduce occupational dose. Both types of techniques are described in more detail below and summarized in Table II.

Minimize Fluoroscopy Time

Fluoroscopy should be used only to observe objects or structures in motion. Review the last-image-hold for study, consultation, or education instead of additional fluoroscopic exposure. If available, use fluoroscopy loop recording to review dynamic processes. Use short taps of fluoroscopy instead of continuous operation. Fluoroscopy to determine or adjust collimator blade positioning can be eliminated by using the virtual collimation feature, when present.

Minimize the Number of Acquired Images

Dose rates during image acquisition are substantially higher than during fluoroscopy, and the number of images acquired has a great effect on patient and operator dose. The total number of acquired images in an interventional cardiology procedure depends on the total time that images are acquired (i.e., number of runs and the time per run) and the frame rate during the acquisition. The number of runs and the time per run should each be the minimum required to achieve the clinical purpose. Many interventional cardiology imaging systems offer a range of frame rates, and the choice should be dictated by clinical needs. As a general rule, the slower the frame rate, the lower the patient dose for a given run time. However, image quality must be adequate. For example, if your equipment has sufficient image quality at 7 or 15 frames/s, use this option instead of 25 or 30 frames/s. A qualified medical physicist should be consulted to advise on the dose/image quality implications of the options on your particular equipment.

Use Available Operator-Selectable Patient Dose Reduction Technologies

These include low dose rate modes for fluoroscopy, low pulse-rate fluoroscopy options, low dose per frame settings for image acquisition, and low frame rate options for image acquisition. Improved image processing within the fluoroscopic unit can compensate to a considerable degree for the reduced image quality due to decreased exposure levels. Some of the terminology can be confusing; hence, it is important to take the time to consult with a qualified medical physicist to gain an understanding of the options and modes available, and their implications for dose rate and image quality. In this way, appropriate choices can be made for your particular equipment and your clinical needs. Catheters with highly radiopaque tips are easier to see. Young children can be imaged without the anti-scatter grid, noting that this technique reduces dose at the cost of somewhat decreased image quality.

Use Good Imaging-Chain Geometry

Place the image receptor (image intensifier or flat panel) as close as possible to the patient's thorax. Work with the patient support as high as possible when in the PA projection so that the patient's back is as far as possible from the X-ray tube. For lateral and oblique projections, special attention should be paid to the geometry—again, tube as far away from the patient, and image receptor as close as possible. Avoid, if not strictly necessary, extreme C-arm angulations that require high dose rates.

Use Collimation

Adjust collimator blades tightly to the area of interest. Tight collimation reduces patient dose, improves image quality by reducing scatter, and reduces occupational exposure by reducing scatter—a win, win, win situation! Utilize the virtual collimation option if it is available. Using semi-transparent or wedge filters also improve image quality and reduces patient and scatter doses.

Position Yourself in a Low-Scatter Area

Depending on your role in the cardiac laboratory, there are several ways to position yourself in a low-scatter area. Stay as far away from the X-ray beam as possible. Never place your hands in the X-ray beam. Use power injectors for contrast material injections when feasible and, during image acquisitions, step back, preferably behind shielding. When using angulated or lateral projections, keep in mind that the highest intensity of scattered radiation is located on the X-ray beam entrance side of the patient. Cranial left anterior oblique projections result in high levels of scatter to the operator.

Use Protective Shielding

Use all personal protective devices available to you. When you perform interventional cardiology procedures, you should always wear a personal protective wrap-around apron and a thyroid shield. Ceiling-suspended shields provide significant additional dose reduction, especially to unprotected areas of your head (eyes) and neck. Leaded eyewear is recommended if ceiling-suspended shields cannot be used continuously during the entire procedure. Under-table lead drapes reduce lower extremity dose substantially and should be used whenever possible.

Use Appropriate Imaging Equipment

It is important that interventional cardiology procedures are performed on equipment designed for, and optimized for, the cardiac procedures to be performed. Furthermore, high-radiation-dose procedures should be performed with imaging systems that incorporate recommended dose-reduction technology and comply with current international standards. Encourage your institution to purchase this kind of equipment for your interventional cardiology laboratories, and ensure that all operators fully understand how to operate the equipment.

Use Imaging Equipment Whose Performance is Controlled Through a Quality Assurance Program

It is important that new imaging equipment is commissioned correctly on acceptance, so that its features and options can be set up, and protocols established, to ensure that the image quality/patient dose relationship is optimized. A system of quality assurance with periodic quality control tests is also needed to ensure on-going acceptable performance of the imaging equipment.

Obtain Appropriate Training

Appropriate training in radiation protection is essential to ensure safe practice in the interventional cardiology laboratory. This should be available at your facility, ideally as part of a formal program [5]. If not, alternative means are needed to ensure that appropriate education and training are obtained before a person performs interventional cardiology procedures. Training programs should include both initial training for all incoming staff and regular updating and retraining. All staff involved in interventional cardiology procedures should have a general knowledge of safe operating practices in a radiation environment. You must be thoroughly familiar with the operation of the particular imaging equipment you are using.

Wear Your Dosimeters and Know Your Own Dose

You need to know your occupational dose to ensure that you are working safely. Your dose data will not be accurate unless you always wear your dosimeters, and wear them correctly.

MANAGEMENT RESPONSIBILITIES

Management should provide an appropriate level of resources, such as staff, facilities, and equipment, to ensure that occupational dose is adequately controlled. Typically, a radiation protection programme (RPP) is used as a means for implementing occupational radiation protection through the adoption of appropriate management structures, policies, procedures, and organizational arrangements. Each interventional cardiology facility needs to have a RPP which should include, but not be limited to, the following: assignment of responsibilities for occupational radiation protection and safety to individuals or to positions within the organization; local rules and procedures for interventional cardiology personnel to follow when using radiation; arrangements for the provision of personal protective equipment; arrangements for individual and workplace monitoring; and a program for education and training in radiation protection and safety. Specific guidance on establishing a comprehensive RPP for a cardiac catheterization laboratory, including occupational radiation protection, has been given by SCAI [5].

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